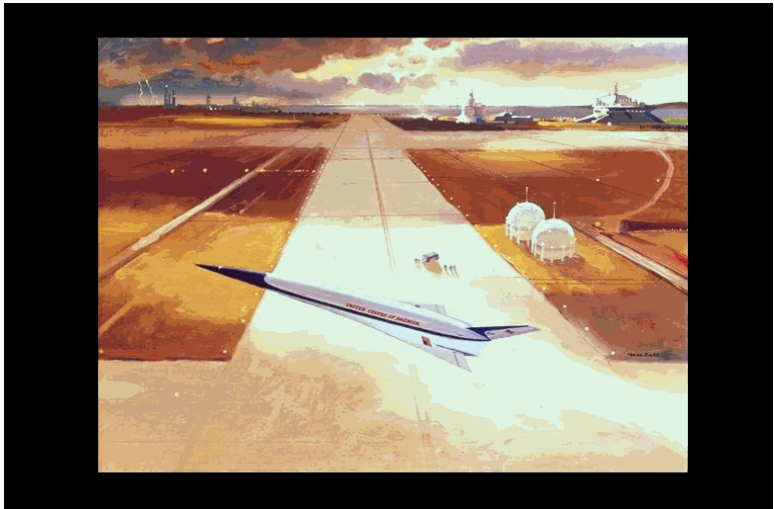


		<i>Structures/Mechanical</i>	<i>Payload</i>	<i>Ground Supportability</i>
<b>Integrate</b>		<ul style="list-style-type: none"> <li>▣Cross sections of tankage/load bearing structure to reduce closed compartments &amp; aeroshells (1, p4)</li> <li>▣Tankage and TPS to eliminate aeroshells &amp; closed compartments (2, p30-31, p39-40)</li> <li>▣Tanks for common fluids (LOX, LH2, GHe...) (2, p37)</li> <li>▣Tanks for multiple systems (MPS, OMS, RCS, power, thermal management) (1, p3) (2,p34-35) (3)</li> </ul>	<ul style="list-style-type: none"> <li>▣Payload containment with the vehicle structure &amp; outer mold line function (5)</li> </ul>	<ul style="list-style-type: none"> <li>▣Flight to ground interfaces (1, p9)</li> <li>▣Components of launch umbilical (electrical connectors, fluid disconnects, structure,...) (5)</li> <li>▣Ground test, launch, and flight control software (5)</li> <li>▣Processing facility and control room infrastructure (4, Gen15)</li> <li>▣Loading umbilicals (fill, drain, power, comm,...) and tank vents (GOX, GH2) into same umbilicals at base (5).</li> </ul>
<b>Eliminate</b>		<ul style="list-style-type: none"> <li>▣Toxic waterproofing for TPS (2, p22-24) (5)</li> <li>▣Need for waterproofing TPS (2,p22-24) (5)</li> <li>▣Complex heat shielding (5)</li> <li>▣Hazardous pyrotechnic/ordnance devices (5)</li> <li>▣Closed structural compartments (without compromising safety and maintainability) near tanks, around MPS manifold, and near areas containing systems which are prone to outgassing or leakage. (2, p30-31, p39-40) (3) (5)</li> <li>▣Unnecessary penetrations in pressurized compartments (4,TC1)</li> <li>▣Mechanical joints (3)</li> </ul>	<ul style="list-style-type: none"> <li>▣Access/entry for removal of integrated cargo element (5)</li> <li>▣Dependence of payload support on launcher (5)</li> <li>▣Fluid interfaces between payload and launcher (5)</li> <li>▣Electrical interfaces (power and communication) between payload and launcher (5)</li> <li>▣Monitoring of payload during cruise phase (5)</li> </ul>	<ul style="list-style-type: none"> <li>▣Toxic fluids for servicing, manufacturing, assembling, and cleaning (1, p4,8) (2, p22-24, 58-59,68)</li> <li>▣High parts count (1, p6) (2, p63-64)</li> <li>▣Large support staff (1, p5)</li> <li>▣Hands-on, intrusive ground support activity (1, p10) (2, p52-54) (5)</li> <li>▣Hard-line data links from vehicle to launch pad and LCC (5)</li> <li>▣Need for complex sound suppression systems (5)</li> <li>▣Swing arms / arm type vents at pad and ordnance / events at launch (3, p30,37,39) (5)</li> <li>▣Vehicle cannibalization (5)</li> </ul>
<i>Design In</i>	<b>Maintainability</b>	<ul style="list-style-type: none"> <li>▣Accessibility without requiring special GSE, access kits, or non-affected line replaceable unit removal (1, p6)</li> <li>▣Fluid/gas connections that do not require process control (i.e. leak-checking) <i>after</i> assembly (1, p11) (2, p44-47)</li> <li>▣Robustness and/or Built-in-Test and verification devices to verify/assure structural safety (2, p27-28) (5)</li> <li>▣Common fasteners (5)</li> <li>▣Robustness and/or TPS quick removal and replacement (2,p53) (4, p48)</li> </ul>	<ul style="list-style-type: none"> <li>▣Standard payload interfaces (5)</li> <li>▣Standard communication/data protocols (5)</li> <li>▣Fluid/gas connections that do not require process control (i.e. leak-checking) <i>after</i> assembly (1, p11) (2, p44-47)</li> <li>▣Built-in-tests to verify payload health (5)</li> <li>▣Minimum attachment interfaces (5)</li> <li>▣Minimum number of different fluids (5)</li> <li>▣Minimum wire count (5)</li> </ul>	<ul style="list-style-type: none"> <li>▣Minimum test hardware interfaces, utilize built-in-test to verify launch readiness (5)</li> </ul>
	<b>Reliability</b>	<ul style="list-style-type: none"> <li>▣Corrosion resistant materials (5)</li> <li>▣TPS that does not require routine inspection (2,p53) (5)</li> <li>▣Minimum parts count (2,p63-64) (5)</li> <li>▣Minimum susceptibility to critical fatigue (5)</li> </ul>	<ul style="list-style-type: none"> <li>▣Commercial off-the-shelf products produced in high quantities (bus, electronics, power, actuators,...) (1, p5)</li> </ul>	<ul style="list-style-type: none"> <li>▣Commercial off-the-shelf (COTS) products produced in high quantities (quick disconnects, valves, software, controllers, PLCs, sensors,...) (2,p41-43) (5)</li> </ul>
	<b>Margin</b>	<ul style="list-style-type: none"> <li>▣Margins in structures that eliminate intrusive inspections for corrosion, primer, defects (5)</li> <li>▣Robust, weather tolerant TPS (2, p22-24)</li> <li>▣Robust, weather tolerant windows (5) (2,p13-16,p25-26)</li> </ul>	<ul style="list-style-type: none"> <li>▣Performance to provide for payload flexibility and growth (1, p12) (2, p58-59)</li> </ul>	<ul style="list-style-type: none"> <li>▣Ground systems robust to failures through redundancies for critical systems (5)</li> <li>▣Ground/flight sys. with requirements capable of being satisfied by wide array of COTS products (5)</li> </ul>
<b>Automate</b>		<ul style="list-style-type: none"> <li>▣Leak <i>location</i> / diagnostics (not just detection) (3)</li> <li>▣Landing gear ground (test) operations (4, GNC8)</li> <li>▣Add / build in integrated vehicle health management (IVHM) systems (4, GNC 13)</li> <li>▣Brake/anti-skid test and checkout (4, GNC9)</li> </ul>	<ul style="list-style-type: none"> <li>▣Checkout of payload interface to vehicle (4, p33)</li> <li>▣Cruise operations (5)</li> <li>▣Scientific data collection and distribution process (5)</li> </ul>	<ul style="list-style-type: none"> <li>▣Maintenance tracking and scheduling to subsystem level (5)</li> <li>▣Failure reporting system (5)</li> <li>▣Launch processing operations and mission planning (5)</li> <li>▣Flight crew active control functions (5)</li> <li>▣Checkout and troubleshooting of flight to ground interfaces (fluid, power, communication, and structural) (5)</li> <li>▣Ground System Checkout &amp; troubleshooting (5)</li> <li>▣Loading/servicing of launch vehicle (5)</li> </ul>

## REFERENCES

1. [Architectural Assessment Tool](#), Space Propulsion Synergy Team (SPST), Oct., 1997.
2. [A Guide for the Design of Highly Reusable Space Transportation](#), SPST, Aug., 1997.
3. [Operationally Efficient Propulsion System Study \(OEPSS\)](#), Rocketdyne Division, Rockwell International, Aug., 1993.
4. [Shuttle Avionics Testing Constraints and Considerations](#), Carey McCleskey, NASA Kennedy Space Center, June, 1995.
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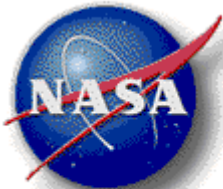
## DESIGN GUIDELINES

- A. Reduce the overall number of different fluids; do not use toxic fluids.
- B. Integrate propulsion system components.
- C. Use reliable, commercial off-the-shelf products that are produced in high quantities.
- D. Automate checkouts of systems and turnaround facilities.
- E. Design for accessibility without requiring special GSE, access kits, or non-affected line-replaceable unit removal.
- F. Minimize interfaces between flight and ground.

		<i><b>Propulsion</b></i>	<i><b>Avionics</b></i> <i>(GNC, communication, computing, power management)</i>
<b>Integrate</b>		<ul style="list-style-type: none"> <li>■MPS and OMS engine function (1, p3) (2, p34-35,72) (3) (5)</li> <li>■OMS and RCS tanks (1, p3)</li> <li>■Oxidizer for MPS, OMS, RCS, power, thermal management (1, p8) (2, p22,34,58)</li> <li>■Fuel types, use identical fuel grades for common fluid systems (2, p58) (5)</li> <li>■Interfaces (connectors/quick disconnects) between flight and ground (3) (5)</li> <li>■N-turbopumps with X-engines to minimize the count of turbopumps (shared turbopumps) (2, p72) (3) (5)</li> <li>■Engine controllers (share with engines and/or avionics) (3)</li> </ul>	<ul style="list-style-type: none"> <li>■Hardware (avionics controls with engine controller, vehicle health system, or ground equipment) (3)</li> <li>■Electrical connectors between flight and ground (5)</li> <li>■Navigation equipment and traditional direct air-stream sensing (4, GNC16)</li> </ul>
<b>Eliminate</b>		<ul style="list-style-type: none"> <li>■Toxic propellants (1, p8) (2, p22-24,68) (5)</li> <li>■Confined spaces with hazardous fluid potential (2, p30-31,68) (3) (5)</li> <li>■GHe/GN2 purges for confined spaces (1, p 6) (2, p39-40)</li> <li>■Confined spaces requiring environmental conditioning (1, p 6) (2, p 39-40)</li> <li>■Fluid joints and electrical conductor counts (2, p58-59)</li> <li>■Large number of gases for flight operations (1, p9)</li> <li>■Active engine events during flight (staging, mixture ratio changing, throttling, mode changes) (1, p4) (3)</li> <li>■Turbopump inner seal purge (2, p44-45) (3)</li> <li>■LOX pump seal leakage (3)</li> <li>■Helium gas usage, pneumatic valve actuators (5) (3)</li> <li>■Helium gas usage for pressurization (3)</li> <li>■Leak potentials (minimize) (3)</li> <li>■Distributive hydraulic systems (1, p8) (2, p22-24,68) (5)</li> </ul>	<ul style="list-style-type: none"> <li>■Toxic cooling fluids, such as freons, ammonia (1,p8) (2, p22-24,58-59,68)</li> <li>■Need for multiple telemetry formats (downlink and downlist) (4, Gen2)</li> <li>■Active cooling for avionics boxes (4, Gen3)</li> <li>■Checkout requirements due to connector demates/remates (4, Gen4)</li> <li>■Possibility of engine collision (4, GNC2)</li> <li>■Procedural restrictions on actuator movement (4, GNC5)</li> <li>■Special cleaning/access requirements (such as for the star tracker lens and light shade inspections) (4,GNC14)</li> <li>■Materials that outgas (4,GNC15)</li> </ul>
<i><b>Design In</b></i>	<b>Maintainability</b>	<ul style="list-style-type: none"> <li>■Built-in-test, troubleshooting, and diagnostics (1, p10) (2, p27-28) (3) (5)</li> <li>■Accessibility without requiring special GSE, access kits, or non-effected line replaceable unit removal (1, p 6) (5)</li> <li>■Minimum number of different propellants (5)</li> <li>■Electro-mechanical actuators (EMA) or electro-hydrostatic (EHA) actuators for gimbalng/TVC (5) (3)</li> </ul>	<ul style="list-style-type: none"> <li>■Minimum fluid interfaces (2, p44-47)</li> <li>■Minimum wire count (4, Gen4)</li> <li>■Minimum connector interfaces (2, p44-47)</li> <li>■Minimum attachment interfaces (5)</li> <li>■Minimum the number of checkouts required (2, p67)</li> <li>■Ergonomic access to line replaceable units (LRU) - accessibility without requiring special GSE, access kits or non-effected LRU removal (4, Gen9)</li> <li>■ Built-in-Tests (BIT) to monitor vehicle health and troubleshoot (5)</li> <li>■ Installation and fastening devices (4, Gen10)</li> </ul>
	<b>Reliability</b>	<ul style="list-style-type: none"> <li>■Commercial off-the-shelf products produced in high quantities (such as electronics, controls, valves, sensors,...) (1, p5) (3)</li> <li>■Expert systems to control complex loading and launch operations (5)</li> </ul>	<ul style="list-style-type: none"> <li>■Commercial off-the-shelf products produced in high quantities (such as software, processors, displays,...) (1, p5)</li> </ul>
	<b>Margin</b>	<ul style="list-style-type: none"> <li>■Operate engines farther from the design edge - less than 100% of design/test thrust rating (2, p25-26)</li> </ul>	<ul style="list-style-type: none"> <li>■In temperature and other operating environment restrictions (4, GNC6)</li> <li>■Hardware immunity to contamination and physical damage (4, GNC15)</li> </ul>
<b>Automate</b>		<ul style="list-style-type: none"> <li>■Turnaround functions, such as leak, valve, electrical, hydraulic, and engine systems checkouts (2, p49-51)</li> <li>■Interface connection/disconnection for fluid and electrical checkouts (5)</li> </ul>	<ul style="list-style-type: none"> <li>■Functions on-board vehicle instead of or in addition to ground (4, Gen6)</li> <li>■Redundant power verification during power-up or system activation (4, Gen13)</li> <li>■Checkout of redundant systems (4, Gen8)</li> <li>■Checkout functions for motorized systems (5)</li> </ul>

# Space Transportation Systems

## Operability



## Quick Reference